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Biological effects of anthropogenic salt-load on the aquatic Fauna: A synthesis of 17 years of biological survey on the rivers Werra and Weser

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ABSTRACT

The reduction and the smoothened amplitudes of the chloride concentrations since 2000 have resulted in a gradual positive development of the aquatic fauna in the River Werra. In the salinized section of the river increasing species numbers have been determined along the salinity gradient, which shows maximum chloride concentrations of about 2500 mg/l, maximum potash concentrations at approximately 200 mg/l, and magnesia concentrations peaked at 320 mg/l. As an immediate consequence of the reduction in salt concentration the immigration of various caddis fly species into the lower River Werra was observed. The Number of taxa per sample rose from 5 to more than 30 in the lower Werra region. Changes in species-richness could be seen more frequently in river sections where chloride concentrations fluctuated around 1500 mg/l.

Introduction

Preface

Since the mid 20th century, the River Werra has been a riverine ecosystem of special significance. The use of the river as a wastewater transport medium for the potash industry in Thuringia and Hessia changed the former freshwater environment into a large, brackish watercourse. Between 1950 and 1970 increased salinity resulted in changes in the river's fauna and flora. Features of the anthropogenic salinity were the discontinuous discharge of saline waste water into the River Werra, and an ionic composition which still differs from natural marine or brackish waters.

The potash industry waste water has a higher content of potash and magnesia. This ionic composition reaches toxic or sublethal levels that threatens most of the aquatic organisms.

Biological investigations in the River Werra are being conducted in the framework a scientific programme that was established in 2004 to document changes in the ecosystem following the reduction of the salt concentration. This scientific and monitoring programme was a part of an approval procedure instituted by the public authorities in Hessia and Thuringia to provide the basis for decisions on the future discharge of salt-water.

Development of chloride- and potash-concentrations

The River Werra has been heavily polluted by salt effluents from the potash industry in Hessia and Thuringia, with maximum chloride concentrations of 27 $g\,l^{-1}$ in 1992 and of 9 $g\,l^{-1}$ in 1997 in the River Werra downstream of the mining region at Gerstungen (Fig. 1). In the period from 1990 to 1992 a reduction in chloride concentration of about 63% was measured in the lower River Werra. High chloride charges and wide amplitudes in chloride concentrations, which drastically affect the ecosystem and the organisms, were the main physiological stressors at that time (DVWK 1998). Since 2000 the salt concentration has been limited to 2500 mg/l Cl^- at Gerstungen by improved techniques and runoff-related input of effluents (Fig. 2). This concentration is actually diluted to a concentration of less than 400 mg/l at the city of Bremen situated some 505 km downstream.

In accordance with the reduced salt concentrations, the amplitudes of chloride concentrations decreased from 5790 to 413 mg/l in the last three decades (Fig. 3) and particularly since 2002.

The main effects of these changes in salt concentration have been the regeneration of the communities of aquatic organisms and the restoration of several ecosystem functions as a result of the decreasing physiological stress (Albrecht 1954; Bäthe 1996 1997a; Koop et al. 1995; Koop 1997).

However, the River Werra still shows high concentrations of potash and magnesia within the zone of main salinisation, which extends about 30 km downstream of Gerstungen. From 2004 to 2007 the maximum potash concentrations were 180–218 mg/l; magnesia concentrations peaked at 320 mg/l (Fig. 4). The thresh-

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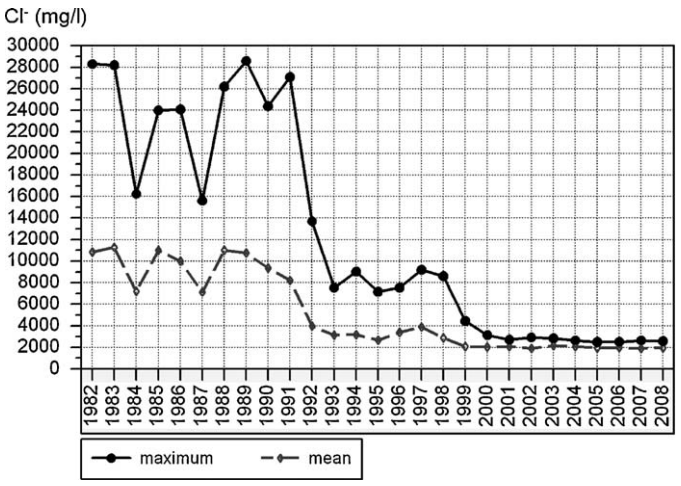

Fig. 1. Long term chloride concentrations in the River Werra at the Gerstungen monitoring site (data from Hessian and Thuringian water resource management authorities, FGG-Weser).

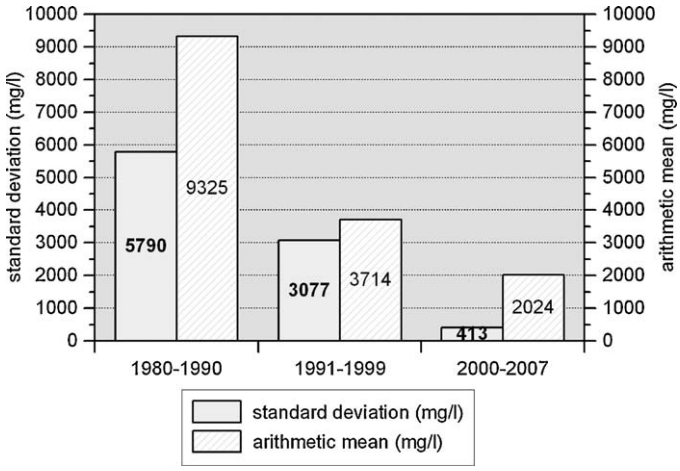

Fig. 3. Amplitudes (standard deviation) of chloride concentrations in the River Werra at the Gerstungen monitoring site 1980–2007 (data from Hessian and Thuringian water resource management authorities, FGG-Weser).

old value of potash concentration for fish toxicity is stated to be 80 mg/l (Halsband 1976).

Dissolved nutrients

Besides the salt concentration, there is a persistent high quantity of nutrients dissolved in the water of the River Werra (FGG Weser 2004). For example at the Gerstungen monitoring site Nitrogen concentrations varied between 1.35 and 20.7 mg/l, the total phosphorus concentrations were 0.12–0.85 mg/l in the time period from 2005 to 2007 (Dietrich and Schumann 2006; Thüringer Landesanstalt für Umwelt und Geologie 2007; Bäthe 2009). The River Werra exhibits a phytal biomass production that is many times greater than in other rivers of similar size (DVWK 1998; Bäthe 2009; Coring and Bäthe this volume). The autotrophic biomass production has increasingly affected water quality in the rivers Werra and Weser with so-called secondary pollution. Decreasing the anthropogenic nutrient influx is one selective measure to avoid further oxygen deficits within the impounded stretches, in order to improve the ecological quality of these rivers (Bäthe and Coring 2002; Herbst 1995). The measured nitrogen concentrations exceeded 3 mg/l at all monitoring sites in the investigation period. An elevated nitrogen pollution was even determined in the river section upstream from the main salinization zone. The measured phosphorous concentrations of the River Werra section between the cities of Breitungen and Hann. Muenden also exceeded values of 0.15 mg/l. Neither the nitrogen nor the phosphorous concentrations limited algal or macrophyte growth in the River Werra at any time. Effluent discharge maintains a high level of nutrients and decomposing organic substances, which shape the environment for the aquatic invertebrate fauna, in the river.

Material and methods

Investigational area and monitoring sites

The investigation area lies in the Central German Uplands near the geographical centre of Germany. At this location the middle and lower River Werra flow through the border region between the German States of Thuringia and Hessia to ultimately become the Weser at the confluence with the Fulda in Lower Saxonia. Since 2002 an approximately 185 km long river section between Breitungen und Hedemünden has been investigated regularly with regard to seasonal aspects. A continuation of the monitoring until well into 2013 is planned.

A total of five permanent monitoring sites were established on this section of the river and have been investigated since 1993. The monitoring sites had been part of the water quality assessment programmes of the responsible supervisory authorities of the states of Thuringia and Hessia before. Since 2007 four additional monitoring

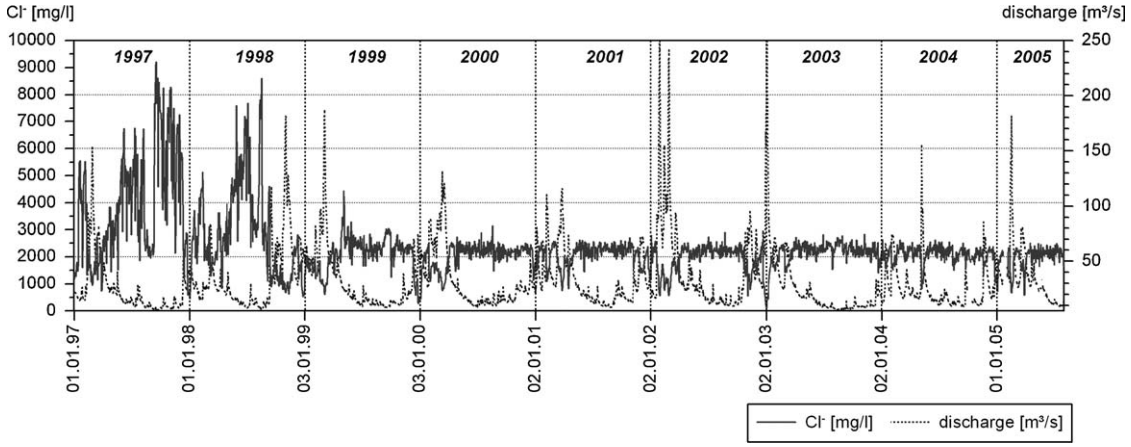

Fig. 2. Chloride concentrations (daily data in [mg/l]) and discharge (daily average values from continuous measurement in [m^3/s]) in the River Werra at the Gerstungen monitoring site 1997–2005 (data from Hessian and Thuringian water resource management authorities, FGG-Weser).

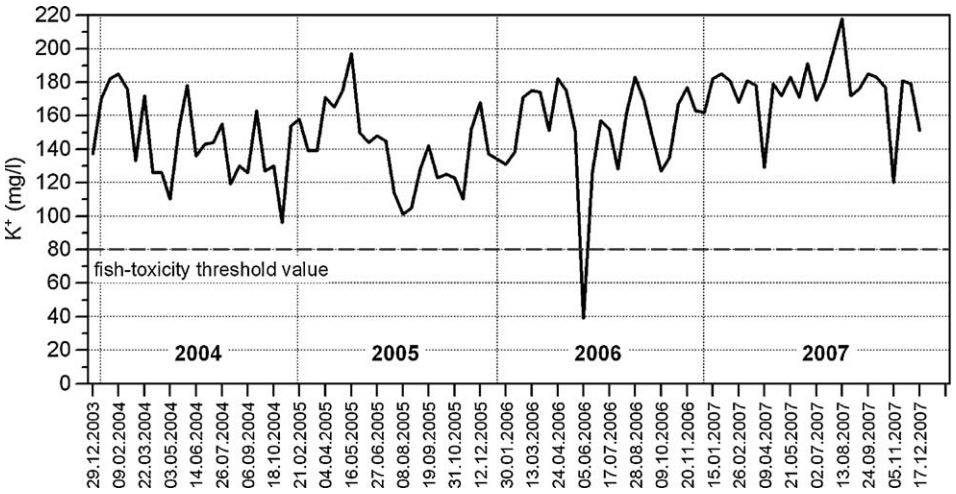

Fig. 4. Potash concentrations in the River Werra at the Gerstungen monitoring site 2004–2007 (data from Hessian and Thuringian water resource management authorities, FGG-Weser).

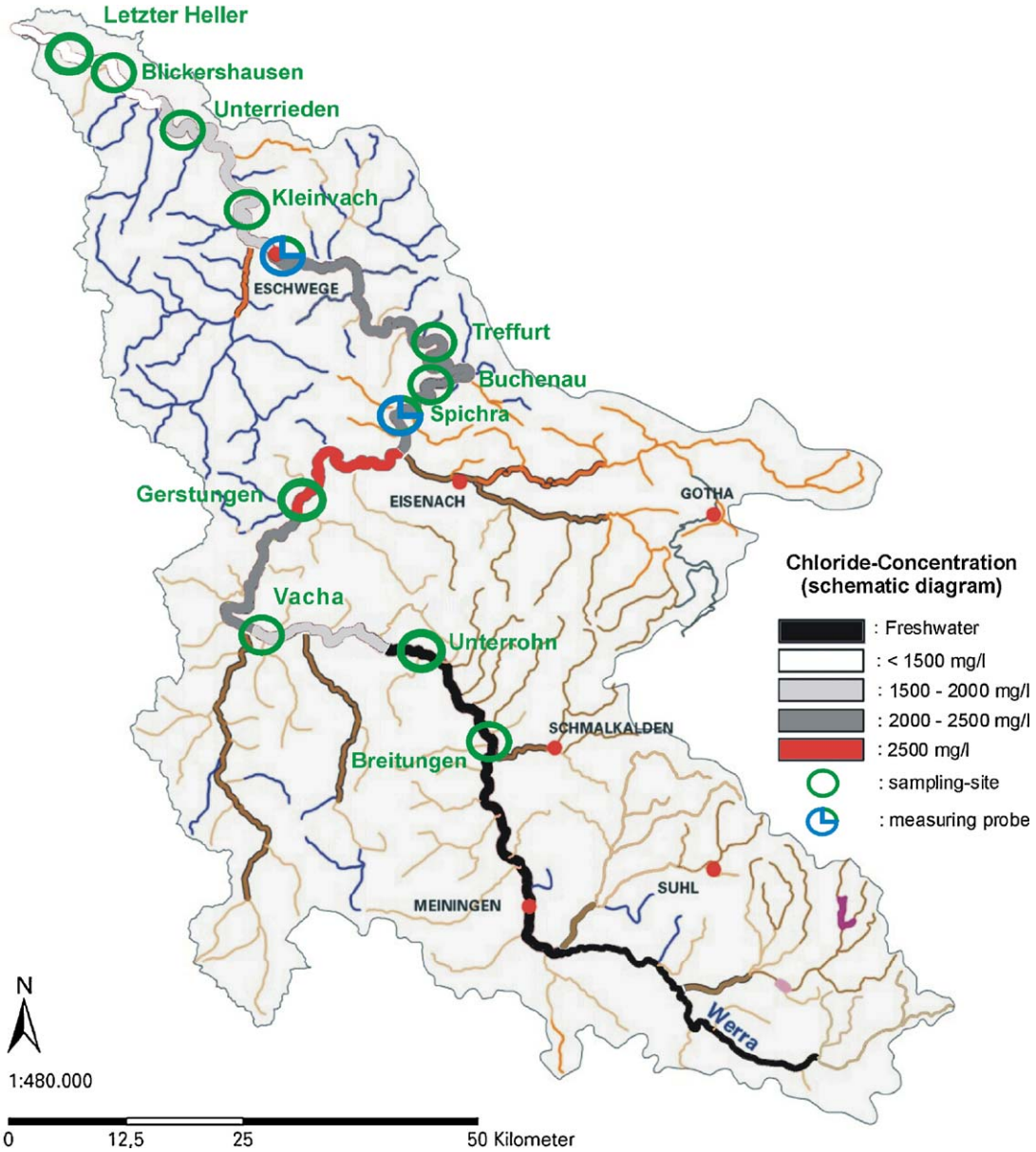

Fig. 5. Overview of the position of the monitoring sites in the Werra region.

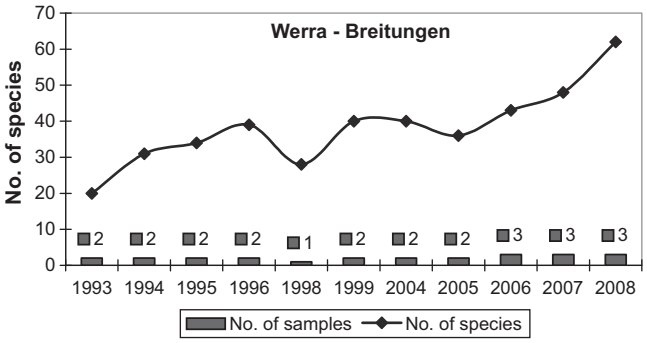

Fig. 6. Development of taxa numbers at the Breitungen monitoring site (Thuringia) 1993–2008.

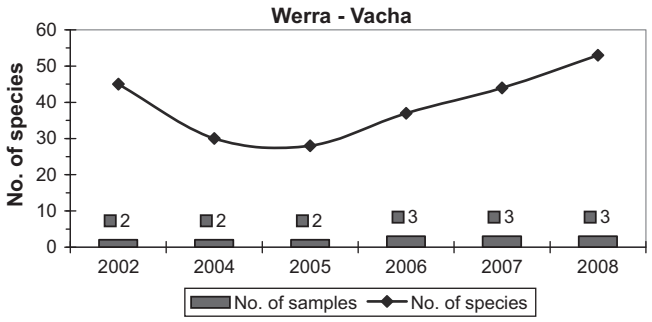

Fig. 8. Development of taxa numbers at the Vacha monitoring site (Thuringia) 2002–2008.

sites have been established to augment the monitoring programme. Fig. 5 provides an overview of the monitoring sites.

Data basis and methods

The quantitative investigations of the macrozoobenthos were carried out in two or three seasonal investigation periods per year. These studies were conducted in accordance with the methods described by Tittizer and Schleuter (1986). This sampling technique, which is performed from the bank, was supported by qualitative investigations (Bäthe 1992): The qualitative studies were carried out as Multi-Habitat-Sampling in accordance with the European Protocol CEN/TC 230/WG 2/TG 1 N101a (2005). In addition, the technical specifications of the German Protocol DIN 38410 T1 (2004) were taken into account in the sampling. The macroinvertebrates material obtained was identified to the species level, if possible, in the laboratory.

In addition to the field investigations, laboratory experiments were performed about the effects of the ions dissolved in Werra water. Ecotoxicological test series were used to provide insights on the subacute and chronic actions of the saline water on the aquatic invertebrates (see publication in the following issue).

Results and discussion of biological investigations

Development of the aquatic invertebrates

As a result of the rising salt concentrations, the extinction of autochthonous amphipoda species and most of the species of Plecoptera, Ephemeroptera, Mollusca, and Bivalvia was recorded during the 1950s. In order to provide suitable prey for the remaining fish, *Gammarus tigrinus* was deliberately introduced to the River Werra as a halotolerant invasive species (Schmitz 1960). Concurrently *Gammarus tigrinus* immigrated from the Weser estuary into the middle Weser and began spreading upstream (Bulnheim and Scholl 1980; Bulnheim 1984). The aquatic biocenosis of the rivers Werra and Weser thus adapted to brackish water conditions (Bäthe 1992, 1995, 1996, 2009).

Change in species numbers

As a result of high salt concentrations, a decrease in species richness was observed in the salinized section of the River Werra, but the benthic biocoenosis also shows a higher diversity in areas having heterogeneous structure and habitats (Bäthe 1992; Eggers 2006). The number of taxa determined at the specific monitoring sites has been increasing, especially since 2002. The freshwater monitoring site at Breitungen (Thuringia) showed an increased number of taxa between 1993 and 1996 (Fig. 6), which was a period of decrease in saprobiological pollution. In 2008 at least 62 taxa were identified. At this location the mayfly and stonefly larvae of *Baetis rhodani*, *Baetis vardarensis*, *Heptagenia sulphurea*, *Serratella ignita* and *Torleya major* as well as *Isoperla grammatica* were observed in higher densities throughout the entire period. Since 1995 approximately 30 taxa were recorded from each individual sample (Fig. 7). This observation indicates that the macroinvertebrate communities have stable population structures.

In the study area near Vacha a recovery of the species numbers has been observed (Fig. 8). However, in 2004 and 2005 the levels

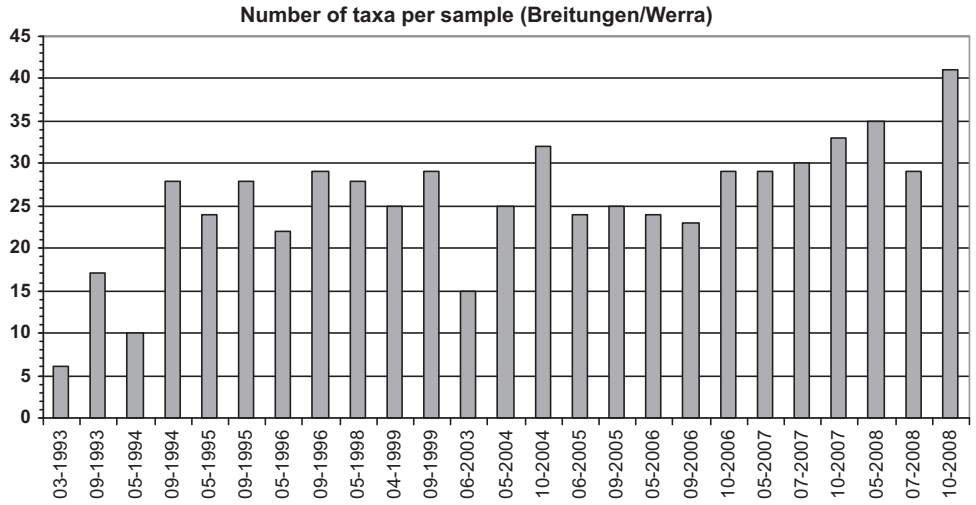

Fig. 7. Number of taxa per sample at the Breitungen monitoring site (Thuringia) 1993–2008.

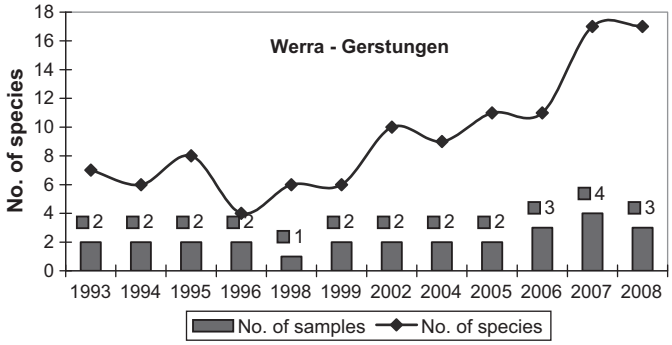

Fig. 9. Development of taxa numbers at the monitoring site Gerstungen (Thuringia) 1993–2008.

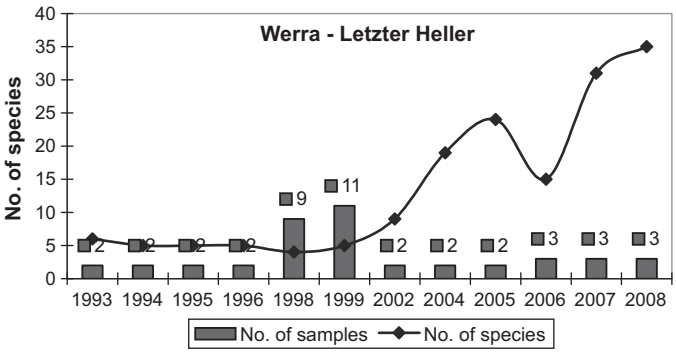

Fig. 11. Development of taxa numbers at the Letzter Heller monitoring site (Hessia) 1993–2008.

were lower. Possible causes are to be found in the variable salt concentrations and reduced waste water discharges subsequent to the new construction of a waste water treatment plant. The chloride concentrations of this river section were 680–1200 mg/l in 2004, up to 1518 mg/l in 2005, and up to 1117 mg/l in 2006. In 2007 and 2008 a maximum of 1062 mg/l was measured.

Among the species with low salt tolerance (Bäthe 1992, 1996, 1997a,b, 1998) which settled in this area were the caddis flies *Cheumatopsyche lepida*, *Cyrnus trimaculatus*, *Hydropsyche contubernalis*, *Hydropsyche pellucidula*, *Hydroptila* spp., *Lasiocephala basalis*, *Polycentropus flavomaculatus* and *Psychomyia pusilla*. The presence of the dragonfly species *Calopteryx splendens*, which has resided in this section of the River Werra since 2004, is noteworthy because of its absence for the previous four decades. In view of the existing salt load, the macroinvertebrate coenosis of the River Werra section at Vacha represents an ecotone. A slight increase in the salt concentration would result in an immediate faunistic impoverishment (Bäthe 2008; DVWK 1998).

Such depletion could be observed in the salinized section of the River Werra between the conjunction with the Ulster and the Gerstungen region (Fig. 9). The predominant species there were the halotolerant taxa *Gammarus tigrinus*, Oligochaeta and various Chironomidae. Among the few salt-tolerant spring residents at Gerstungen were *Elmis maugetii*, *Hydropsyche angustipennis*, *Hydropsyche pellucidula*, *Hydropsyche siltalai*, *Hydroptila* spp. und *Psychomyia pusilla*; the population densities reached up to 32 ind/m^2. Among the turbellarians of the study area were *Polycelis tenuis* as well as the milky white turbellarian *Dendrocoelum lacteum*.

The number of verified taxa shows that the Gerstungen area is a faunistically impoverished river section. Until 1999 merely 4–9 taxa with; in part; large individual densities in the course of the year could be found here. Immediately after the commissioning of the salt concentration control system and the accompanying uniformization of the salt concentrations, the species numbers in the River Werra at Gerstungen could be seen to double. In the years 2007 and 2008 17 taxa had already been verified (Fig. 9). However, the macroinvertebrate community is instable as can be seen in the number of the respectively identified taxa of an investigation (Fig. 10).

In addition to the firmly established mud shrimp *Corophium lacustre* and the amphipod *Gammarus tigrinus*, the following species are part of the macroinvertebrate community of the lower River Werra in the impounded section of the Letzten Hellers: *Asellus aquaticus*, *Proasellus coxalis*, *Dendrocoelum lacteum*, *Dugesia gonocephala*, *Dugesia lugubris*, *Oulimnius tuberculatus*, *Potamopyrgus antipodarum* as well as various Oligochaeta and Chironomidae. In 2005 the caddis fly genus *Tinodes* was verified for the first time in the Letzter Heller area. Since 2007 the following, additional caddis fly species are present: *Cheumatopsyche lepida*, *Hydropsyche angustipennis* and *Hydropsyche contubernalis*.

The effect of the salinity load control system is also apparent in the lower River Werra. In the Letzter Heller region the species number rose from 5 (until 1999) up to 35 (2008) (Fig. 11). This positive development in the morphologically degraded impounded section of the river is exceeded in the structure-rich section at Blickershausen, which lies immediately above the former.

The Blickershausen study area is located above the Letzter Heller storage level regulation area in the section which is still free-flowing. Due to the higher morphological diversity of the habitats

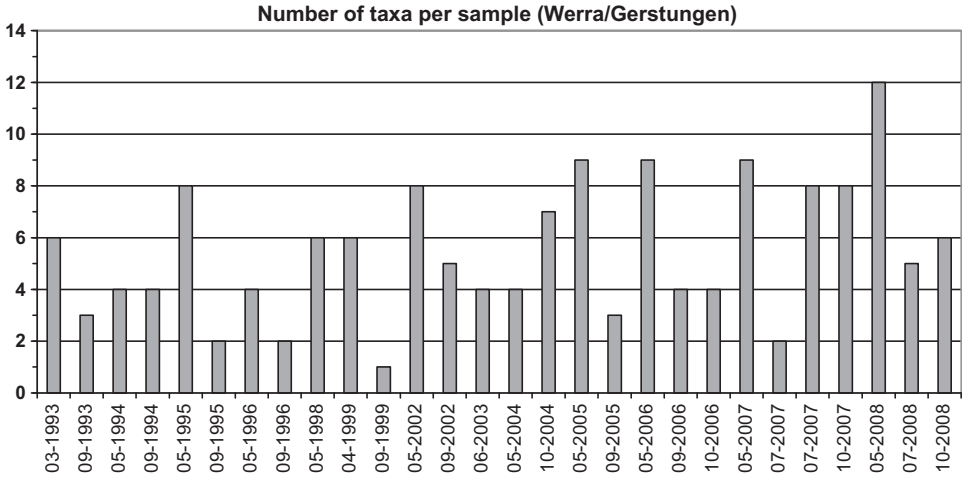

Fig. 10. Number of taxa per sample at the Gerstungen monitoring site (Thuringia) 1993–2008.

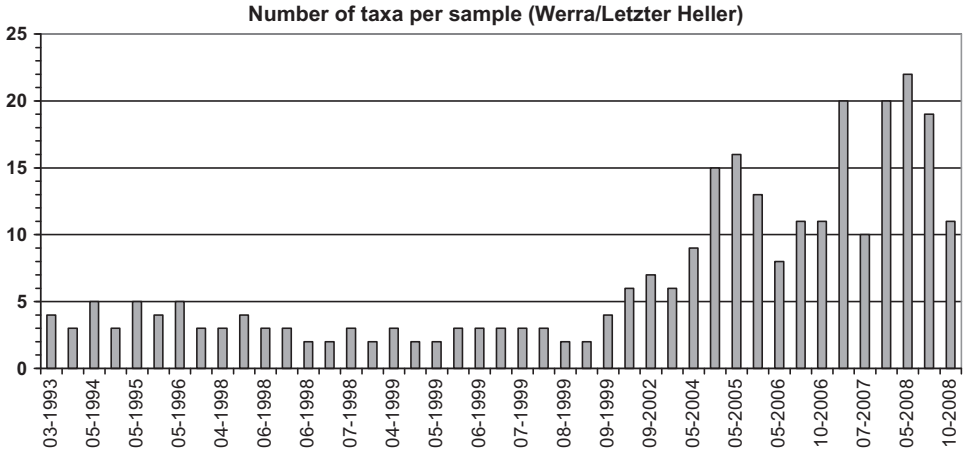

Fig. 12. Number of taxa per sample at the Letzter Heller monitoring site (Hessia) 1993–2008.

there and the higher flow velocity, 43 species were identified in this study area in 2007. In light of the spatial proximity to the Letzter Heller monitoring site, water quality can be ruled out as a population-determining factor.

Among the species found there are the following: the caddis flies *Agraylea* spp., *Cheumatopsyche lepida*, *Hydropsyche angustipennis*, *Hydropsyche exocellata*, *Hydropsyche contubernalis*, *Hydropsyche pellucidula*, *Psychomyia pusilla* and *Rhyacophila dorsalis*; the long-toed water beetles *Elmis maugetii* and *Oulimnius tuberculatus* as well as the turbellarian *Dugesia gonocephala*, which is a typical representative of taxa present in upland brooks and small streams. In total, the species spectrum of the lower River Werra has increased since 2004.

This finding is supported by the species numbers determined in every individual sample (Fig. 12). Until the year 2000 individual samples generally contained less than 5 taxa. In the following years this number initially increased to 15 and then rose further until it reached 22 taxa in the spring of 2008.

Composition of the macroinvertebrate communities

The faunistic changes along the course of the river are illustrated by the variability in the taxonomic groups present. Thus, the salt-pollution-free monitoring sites Breitungen and Unterrohn were characterized by a change of the seasonal aspect of the biocoenosis, which primarily affected the Diptera, Trichoptera, Oligochaeta und Coleoptera.

This change in the seasonal aspect in the salt-polluted river sections is primarily evident in the pronounced increase in the Amphipoda cohort representing the winter population. The salt pollution affects the composition of the invertebrate fauna, above all in the Gerstungen area. Further downstream the diversity of large systematic groups increased again due to dilution effects. Despite comparable species numbers, a structural change in the invertebrate fauna is apparent along the course of the river between Breitungen and Vacha. It is manifested, e.g., in the absence of Ephemeroptera (mayflies) and other sensitive forms (Fig. 13).

In particular in the region of maximum salt concentration between Gerstungen and Spichra the composition of the aquatic invertebrate fauna proved to be impoverished and dominated by *Gammarus tigrinus*. Sections of the further river course with more structure provide an increasing number of habitats appropriate for different groups of organisms (Arbeitsgemeinschaft zur Reinhaltung der Weser 1996, 1998; Bäthe 2008). In interaction with the progressive dilution of the salt concentration, the River Werra biocoenosis experiences an increasing diversity of organisms. The

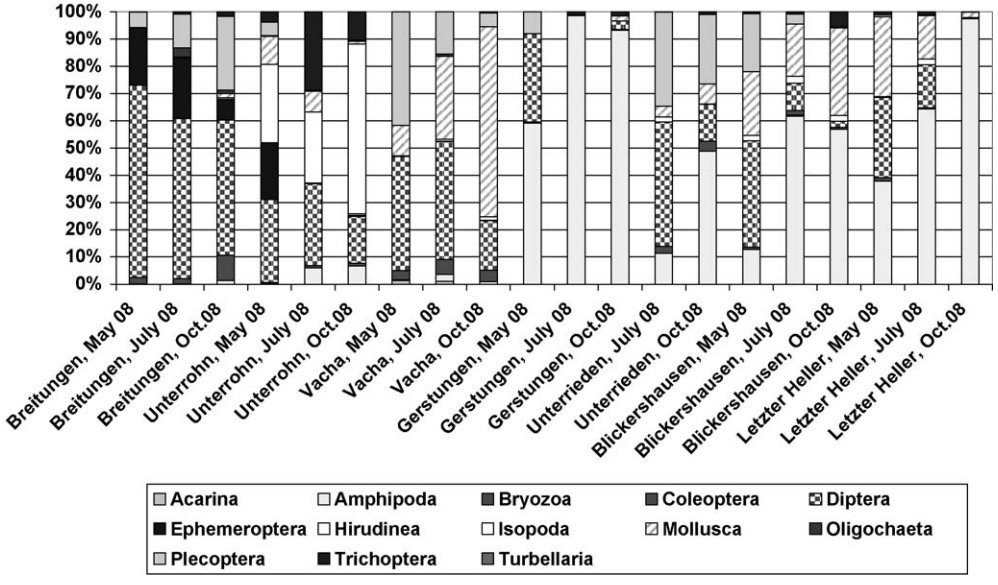

Fig. 13. Proportions of taxonomic groups of the benthic biocoenosis of the examined river sections in 2008.

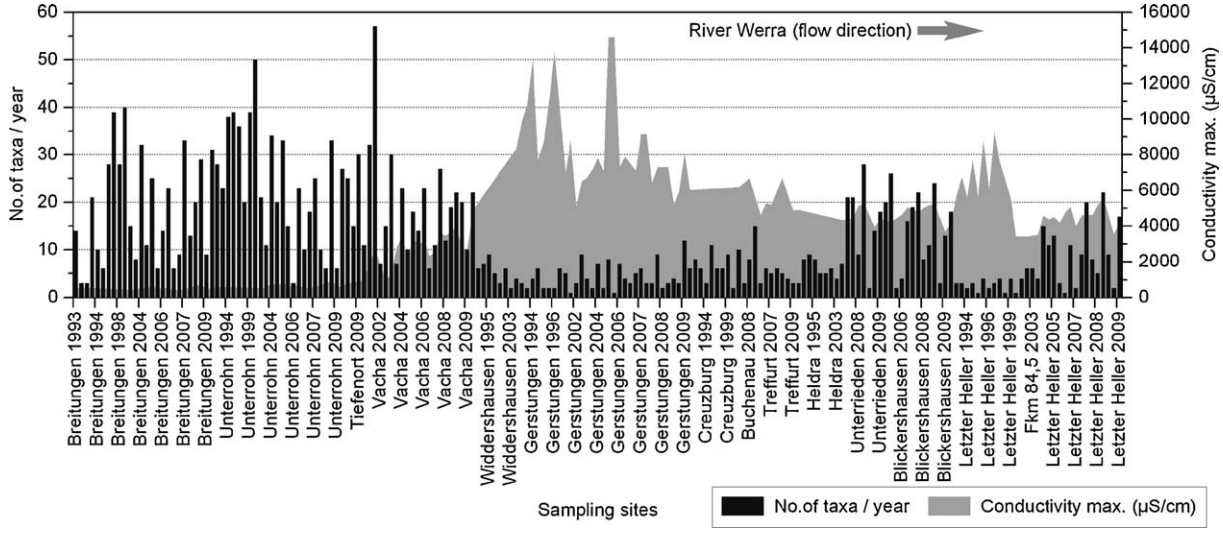

Fig. 14. Number of taxa and electrical conductivity in the River Werra at the macrobenthos sampling sites (1993–2009).

interpretation of taxa-numbers and the corresponding electrical conductivity of each sample indicate a strict dependence of species richness on salinity (Fig. 14).

Above all in the Breitungen region, the trophic structure of the invertebrate community exhibits only small changes in the course of the year (Fig. 15). The high fractions of filter-feeding species there is conspicuous, which allows conclusions of a correspondingly large occurrence of bacteria, algae und organic detritus (Herbst 1996; Schönborn 2003). In the further course of the river the proportions of shredders and sediment feeders increases. The presence of filter-feeders and predators is primarily concentrated in the more structured river sections, such as those found at Buchenau, Kleinvach and Unterrieden. In view of the extensive phytoplankton development in the middle and lower River Werra, the filter-feeders which are absent or only present in low population densities in the less structured regions of the river represent a decisive gap in the food web. This missing function of the benthic biocoenosis results in deficient incorporation and transformation of available biomass. Parts of the material cycle carry the primary production directly to bacterial degradation with a correspondingly elevated oxygen demand. This "short circuit" stresses the aquatic system, which not only affects the lower River Werra, but also the River Weser, which lies directly downstream, to an even greater extent. Findings on different groups of aquatic organisms, their functions and specific development within the aquatic food web of the rivers Werra and Weser are given by Bäthe (1993), Dirksen (1995), Nolting (1996), Rohlfing and Mannesmann (1996), Rustige and Mannesmann (1996), Rustige et al. (1997) and Herbst (2000).

Results and discussion

Conclusion on the development of the macrozoobenthos

From a limnofaunistic point of view, the River Werra is divided into different sections: These sections result from the different environmental conditions, which are due to the rising and sinking salinity gradients.

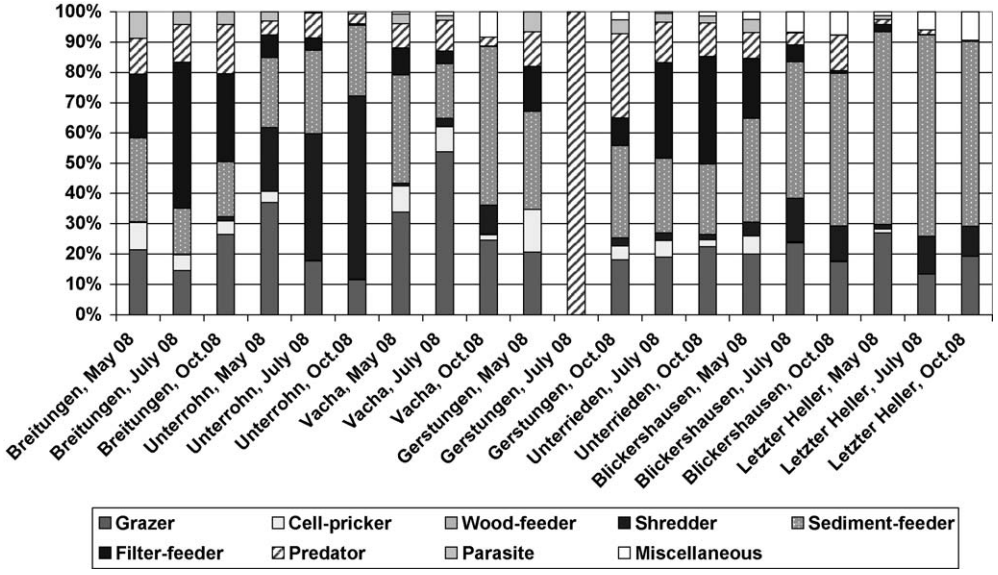

Fig. 15. Feeding types of the macroinvertebrates along the investigated Werra sections in 2008.

As a result of diffuse water influxes, direct salt discharges and dilution from tributaries, the River Werra's salt load is unevenly distributed. In the Unterrohn region low salinities from the use of natural salt deposits can be detected. A further increase in the salinity gradient is due to the diffuse influxes of salt water on the bottom of the River Werra at Tiefenort. The highest salt concentration of the river is reached at Gerstungen after all the industrial salt waste water has been discharged into the river. This zone of maximum salinity stretches for approximately 30 river kilometres up to the junction with the Hörsel, whose water effects a dilution and thus a decreasing salt gradient. In the further course of the river the salt concentration is diluted down to a chloride concentration of 1000–1500 mg/l in the area of the "Letzter Heller's" barrage dam with lock, before the River Werra and the River Fulda join to form the River Weser.

The biologically effective salinity influences the species composition of the invertebrate fauna in the course of the River Werra and represents one of the crucial control parameters in the functional network of the river ecosystem. Comparable studies from Australia (Halse et al. 2003) and France (Piscart et al. 2005a,b) underpin this issue for different rivers. The significant difference between the salinity of the River Werra and other examined salinized rivers is the ionic composition with enhanced concentrations of potassium and magnesia (see publication in the following issue). This distinctive feature of saline waste water charge is found very rarely in other comparable studies.

Since 2002 the reduction and the uniformization of the salt concentrations have allowed a gradual positive development of the macroinvertebrates in the River Werra system. Other stressors, which act on the river ecosystem in addition to the salt concentration; are nutrient pollution, waste water and multifarious structural degradations (Dietrich and Schumann 2006; Thüringer Landesanstalt für Umwelt und Geologie 2007; Bäthe 2009).

Among the above-mentioned stressors, the salt concentration is the only factor which has distinctly changed in a positive sense in the past decade. With regard to waste water pollution the responsible authorities announced the initiation of comparable steps in the next 10 years.

The immediate consequences of the reduction in salt concentration are the immigration of various caddis fly species into the lower River Werra since 2004. The current state is the presence of 8 different Trichoptera species and further taxa with low salt tolerance along a section from more than 60 km length. In addition to various caddis flies, larval stages of *Calopteryx splendens* were found in the main salanized zone in the River Werra. Since 2007 an increasing number of Ephemeroptera, Trichoptera and Coleoptera of the genus *Elmis* have become increasingly evident in river sections with elevated salt concentration. Overall, the faunistic development of the salt-loaded Werra sections exhibit numerous consistencies with the developments in the upper Weser between 1994 and 2001 (Bäthe 2008; DVWK 1998).

Summary

The salt concentration of the River Werra was distinctly reduced at the beginning of the 1990s and in the year 2000. Starting from the strongly oscillating salinities with peak values of 28,000 mg/l chloride, the salt concentration has been strongly uniformized and limited to maximum values of 2500 mg/l since the year 2000. With the reduction of the salt concentration a gradual recolonisation of the rivers Werra and Weser began. The extensive elimination of the concentration fluctuations and the resulting minimization of the physiological stress of aquatic organisms were of decisive importance. Since that time, increasing species numbers in the macroinvertebrate communities have been evident along the decreasing salinity gradients in the River Werra. Among the animals resettling the River Werra are, for example, Trichoptera of the genera *Cheumatopsyche*, *Hydropsyche*, *Psychomyia* und *Rhycophila* as well as beetles of the genera *Elmis* and *Oulimnius*. Besides the salt concentration, additional active stressors are the nutritional and waste water pollution as well as diverse structural degradations of the river course.

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References

Albrecht, M.-L., 1954. Die Wirkung der Kaliabwässer auf die Fauna der Werra und Wipper. Zeitschrift für Fischerei, pp. 401–426.

Arbeitsgemeinschaft zur Reinhaltung der Weser, 1996. Ökologische Gesamtplanung Weser. Grundlagen, Leitbilder und Entwicklungsziele für Weser, Werra und Fulda. Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen (Ed.), Düsseldorf, 1–236, Bezugsadresse. FGG-Weser, An der Scharlake 39, 31135 Hildesheim.

Arbeitsgemeinschaft zur Reinhaltung der Weser (ARGE-Weser), 1998. Gewässerstrukturgütekarte Weser, Werra, Fulda. Thüringer Ministerium für Landwirtschaft, Naturschutz und Umwelt–Vorsitz der Arbeitsgemeinschaft zur Reinhaltung der Weser–Erfurt, 47 S., 32 Karten.

Bäthe, J., 1992. Die Makroinvertebratenfauna der Weser. Ökologische Analyse eines hochbelasteten, anthropogenen Ökosystems. Ekopan-Verlag, Witzenhausen.

Bäthe, J., 1993. Sanierung eines Fließgewässersystems. Die Entsalzung von Werra und Weser - Erste Veränderungen seit 1989 und Reaktionen des Makrozoobenthos. In: Deutsche Gesellschaft für Limnologie (Ed.), Erweiterte Zusammenfassungen der Jahrestagung 1993. H. Kaltenmeier Söhne, Krefeld, pp. 398–402.

Bäthe, J., 1995. Die Makroinvertebraten-Fauna der Weser. In: Friedrich, G., Kinzelbach, R. (Eds.), Die Weser. Limnologie Aktuell, Band 6. G. Fischer Verlag, Stuttgart, pp. 175–190.

Bäthe, J., 1996. Decreasing salinity and initial reactions of the macrozoobenthos in the rivers Werra and Weser. Arch. Hydrobiol., Suppl. 113, Large Rivers 10 (1–4), 305–312.

Bäthe, J., 1997a. Decreasing salinity in Werra and Weser (Germany). Reactions of the phytoplankton and the Makrozoobenthos. Limnologica 27 (1), 111–119.

Bäthe, J., 1997b. Über die Wiederbesiedlung der Weser durch *Ephoron virgo* (Olivier 1791) (Ephemeroptera, Polymitarcidae), *Anodonta anatina* (Linnaeus 1758) und *Unio pictorum* (Linnaeus 1758) (Lamellibranchiata, Unionidae). Lauterbornia 28, 45–50.

Bäthe, J., 1998. Beobachtungen zur Salztoleranz aquatischer Makroinvertebrata des Werra-Weser Systems. In: Deutsche Gesellschaft für Limnologie (Ed.), Erweiterte Zusammenfassungen der Jahrestagung 1997. H. Kaltenmeier Söhne, Krefeld, pp. 946–950.

Bäthe, J., 2008. Veränderungen im salzbelasteten Fließgewässer-Ökosystem der Werra. Ergebnisse langjähriger Untersuchungen des Makrozoobenthos. In: Deutsche Gesellschaft für Limnologie (Ed.), Erweiterte Zusammenfassungen der Jahrestagung in Münster. Hubert & Co., Göttingen.

Bäthe, J., 2009. Weser. In: Tockner, K., Robinson, C.T., Uehlinger, U. (Eds.), Rivers of Europe. Elsevier Ltd., London, UK, pp. 525–533.

Bäthe, J., Coring, E., 2002. Sauerstoffdefizite in großen Flüssen – ein gelöstes Problem? In: Deutsche Gesellschaft für Limnologie (Ed.), Erweiterte Zusammenfassungen der Jahrestagung in Kiel. Hubert & Co., Göttingen, pp. 470–474.

Bulnheim, H.-P., 1984. Biochemische-genetische Untersuchungen zur Art- und Populationsdifferenzierung bei Amphipoden und Isopoden. Zool. Beiträge N.F. 28, 349–368.

Bulnheim, H.-P., Scholl, A., 1980. Evidence of genetic divergence between two brackish-water gammaridean sibling species. Mar. Ecol. Prog. Ser. 3, 163–165.

CEN/TC 230/WG 2/TG 1 N101a, 2005. Water Quality—Guidance on the Selection of Sampling Methods and Devices for Benthic Macroinvertebrates in Freshwaters, p. 28.

Coring, E., Bäthe, J., this volume. Effects of reduced salt concentrations on plant communities in the River Werra (Germany). Limnologica.

Dietrich, J., Schumann, A., 2006. Werkzeug für das integrierte Flussgebietsmanagement. Ergebnisse der Fallstudie Werra. Konzepte für die nachhaltige Entwicklung einer Flusslandschaft, Bd. 7. Weißenseeverlag, Berlin, pp. 452.

DIN 38410-1, 2004. Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung - Biologisch-ökologische Gewässeruntersuchung (Gruppe M) - Teil 1. Bestimmung des Saprobienindex in Fließgewässern. (M 1).

Dirksen, M., 1995. Makrozoobenthos von Werra und Weser - Untersuchung zur Biomasse einer salzbelasteten Biozönose und Erprobung neuer Methoden zur Bewertung limnischer, brackiger Fließgewässer. Diplomarbeit im Fachbereich Biologie der technischen Hochschule Darmstadt.

Deutscher Verband für Wasserwirtschaft und Kulturbau (DVWK), 1998. Folgen der Reduktion der Salzbelastung in Werra und Weser für das Fließgewässer als Ökosystem. Deutscher Verband für Wasserwirtschaft und Kulturbau (DVWK), Bonn, pp. 1–196.

Eggers, T.O., 2006. Auswirkungen anthropogener Strukturen auf die Makrozoobenthoszönose von Schifffahrtsstraßen. Dissertation an der Technischen Universität Carolo-Wilhelmina zu Braunschweig.

FGG-Weser (Flussgebietsgemeinschaft Weser), 2004. Wesergütebericht 2003. Flussgebietsgemeinschaft Weser, Hildesheim, pp. 1–129.

Halsband, E., 1976. Untersuchung über den Krankheitszustand der in der Weser lebenden Fische. Informationen für die Fischwirtschaft 23 (10), 173–175.

Halse, S.A., Ruprecht, J.K., Pinder, A.M., 2003. Salinisation and prospects for biodiversity in rivers and wetlands of south-west Western Australia. Aust. J. Bot. 51, 673–688.

Herbst, V., 1995. Nährstoffbelastung und Sauerstoffhaushalt der Weser. In: Friedrich, G., Kinzelbach, R. (Eds.), Die Weser, Limnologie Aktuell. Gustav Fischer Verlag, Stuttgart/Jena/New York Bd. 6, pp. 67–76.

Herbst, V., 1996. The Weser Salinity Decrease and Initial Reactions of the Phytoplankton. Arch. Hydrobiol., Supplement Large Rivers.

Herbst, V., 2000. Versalzung von Gewässern. In: Guderian, R., Gunkel, G. (Eds.), Aquatische Systeme. Handbuch der Umweltveränderungen und Ökotoxikologie Band 3A. Springer-Verlag, Berlin, pp. 380–398.

Koop, J.H.E., 1997. Survival strategies of Amphipods in Saltpolluted Rivers. Information from Microcalorimetry and ^{31}P NMR spectroscopy. Limnologica 27 (3–4), 307–309.

Koop, J.H.E., Zange, J., Grieshaber, M.K., 1995. Comparative investigations on the effect of environmental salt stress on energy metabolism of amphipods estimated by ^{31}P NMR spectroscopy and microcalorimetry. Thermochim. Acta 251, 45–51.

Nolting, E., 1996. Untersuchungen zur Entwicklung der Aufwuchsciliaten im Wesersystem. In: Deutsche Gesellschaft für Limnologie (Ed.), Tagungsbericht 1995. H. Kaltenmeier Söhne, Krefeld, pp. 660–664.

Piscart, Ch., Lecerf, A., Usseglio-Polatera, Ph., Moreteau, J.-C., Beisel, J.-N., 2005a. Biodiversity patterns along a salinity gradient. The case of net-spinning caddis flies. Biodivers. Conserv. 14, 2235–2249.

Piscart, Ch., Moreteau, J.-C., Beisel, J.-N., 2005b. Biodiversity and structure of macroinvertebrate communities along a small permanent salinity gradient (Meurthe River, France). Hydrobiologia 551, 227–236.

Rohlfing, S., Mannesmann, R., 1996. Bakterienplankton in Werra und Weser. In: Deutsche Gesellschaft für Limnologie (Ed.), Tagungsbericht 1995. H. Kaltenmeier Söhne, Krefeld, pp. 665–669.

Rustige, K.-H., Mannesmann, R., 1996. Verbreitungsmuster sessiler Ciliaten (Ciliophora. Peritrichida, Suktorida, Chonotrichida) in salz- und organisch belasteten Fließgewässern. In: Deutsche Gesellschaft für Limnologie (Ed.), Tagungsbericht 1995. H. Kaltenmeier Söhne, Krefeld, pp. 670–674.

Rustige, K.-H., Friedrich, Ch., Külzer, H.A., 1997. Distribution patterns of sessile ciliates in salt-polluted running water systems. Limnologica 27 (1), 85–90.

Schmitz, W., 1960. Die Einbürgerung von *Gammarus tigrinus* SEXTON auf dem europäischen Kontinent. Arch. Hydrobiol. 57 (1/2), 223–225.

Schönborn, W., 2003. Lehrbuch der Limnologie. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Thüringer Landesanstalt für Umwelt und Geologie, 2007. Die Beseitigung von Abwasser im Freistaat Thüringen. Lagebericht 2006. Jena, August 2007.

Tittizer, T., Schleuter, A., 1986. Eine neue Technik zur Entnahme quantitativer Makrozoobenthos-Proben aus Sedimenten größerer Flüsse und Ströme. Deutsche Gewässerkundliche Mitteilungen 30 (H 5/6), 147–149.